FERMILAB-Conf-93/320-E

CDF

New Particle Searches at CDF

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November 1993

Published Proceedings *International Europhysics Conference on High Energy Physics,* Marseille, France, July 22-28, 1993

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CDF/PUB/CDF/PUGLIC/2302
FERMILAB-CONF-93/320-E

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ABSTRACT

We present a review of the search for new particles, such as leptoquarks, excited quarks, SUSY and top at CDF.

Introduction

The Fermilab $p\bar{p}$ Collider has recently completed the 1992–93 run (Ia). At the end of this run a luminosity of about 22 pb^{-1} was integrated on tape by CDF. This is five times what was previously available. As a consequence, and given the uniquely high E_{cm} of 1.8 TeV, CDF has greatly increased its capability to explore new mass ranges where exotic physics beyond the Minimal Standard Model could appear. Of course the main goal is to discover a major cornerstone of the Standard Model, the top quark. A number of approaches that were developed to search for top will be discussed in this report.

Exotic Physics

Leptoquarks

The symmetry of the quark and lepton families may suggest that quarks and leptons be related at a fundamental level. Leptoquarks (lq), new particles which carry both color and lepton quantum number, appear in almost any theoretical model where a quark–lepton coupling is assumed[1]. Using 4.05 pb^{-1} of data collected during the run 88–89 CDF has searched for evidence of scalar lq pair production in the decay channel into an electron and a quark. Events were selected with two opposite charge, isolated, large P_t (P_t>20 GeV) electrons, and at least two jets with E_t>20 GeV. Three events were found, which however are consistent with Z^0+multijets production. Outside the Z^0 mass region ($75<Z^0<110$) no lq candidates were found. Based on an observation of zero events, assuming the lq mass M_{lq} and the decay branching ratio β for $lq \rightarrow l+q$ ($0<\beta<1$) as free parameters, CDF set a limit on the lq pair production cross section $\sigma^*\beta^2<54.6(4.0)$ pb for M_{lq}=45(125) GeV/c^2 at 95% C.L.[2].

Excited Quarks

If quarks are composite particles, excited q^* states are expected to be produced in $p\bar{p}$ collisions[3]. In the simplest model, an electroweak lagrangian with standard couplings couples q^* to both charged and neutral vector boson, thus allowing $q^* \rightarrow qW$ and $q^* \rightarrow q\gamma$ decays. CDF has searched for q^* by looking for "bumps" in the W+jet effective mass distribution , in the W+jets sample (using a sample of 14 pb^{-1}) and for bumps in the γ+jet mass distribution in the γ+jets sample (22 pb^{-1} from run IA and 3.3 pb^{-1} from run 88–89). Both the γ+jet and W+jet mass spectra are in good agreement with QCD background calculations. One can therefore set an upper limit on the q^* cross section vs. mass and exclude q^*'s (with standard EW–couplings) in the mass range $90<M^*<570$ GeV at 95% C.L.[4].

SUSY

The existing CDF limit on the squark and gluino masses was obtained searching for anomalous production of jet events with large missing E_t, which could signal the presence of undetected photinos[5]. An additional channel bearing a SUSY signature is chargino-neutralino $\chi_1^{\pm}\chi_2^0$ production followed by $\chi_1^{\pm} \rightarrow l\nu\chi_1^0$ and $\chi_2^0 \rightarrow l\bar{l}\chi_1^0$[6], where χ_1^0 is the invisible photino, χ_2^0 is the next to lighest neutralino (Zino) and $\chi_1^{\pm}$ is the lightest chargino (Wino). The signature for this process is three isolated leptons, which may not balance in P_t. 11.1

σ^*BR (pb)	M_{gluino} (GeV)
<3.07	160
<2.35	180
<2.13	200
<1.73	220

Table 1: Cross sections*branching ratios excluded at 95 % C.L. for various gluino masses.

pb^{-1} of electron and muon data from the 92–93 run were analized. There are 2 tri–muon events left after final selection cuts. Assuming tan(β)=5 (ratio of vacuum expectation values of the neutral and charged Higgs bosons), μ=-300 GeV (Higgsino mass mixing parameter), M_H=500 GeV (charged Higgs mass) and squark mass equal to gluino mass, the cross-section times braching ratios in Table 1 were excluded with 95% C.L.. Since in the chosen model there is a nearly linear relationship between the Wino and Zino masses, and the gluino mass, and since the 160 GeV gluino mass value is below the theory prediction, it is also possible to set a lower limit on the Wino mass of 45 GeV[7]. This limit is the same as obtained at LEP.

Top search at CDF

At a hadron collider an heavy top quark ($M_{top}>M_W$) would be dominantly produced in pairs, as $p\bar{p}\rightarrow t\bar{t}X$. In the Standard Model the t quark is expected to decay into a b quark and a W boson ($t\rightarrow Wb$). In a minimal SUSY model a competitive decay $t\rightarrow H^{\pm}b$ would exist[8]. Standard Model $t\bar{t}$ events may give different signatures according to the various decay modes of the two W's in the event. Only the "single lepton" and the "dilepton" channel were exploited so far, corresponding respectively to two direct (mostly) leptonic $W\rightarrow l\nu$ decays and to one leptonic and one hadronic $W\rightarrow q\bar{q}'$ decay. During the 88–89 run CDF collected 4.1 pb^{-1} and set a lower limit of 85 GeV at 95 % C.L. on M_{top} from the dilepton channel alone. When combined with the results from the lepton+jets+b channel, where the b was tagged through a soft lepton generated in its semileptonic decay, an improved limit of 91 GeV/c^2 was obtained[9].

Di–lepton channel

The entire set of new data has been analysed, requiring that the two leptons pass the (20,20) P_t cut. A back to back cut in azimuthal angle ($\Delta\phi_{ll}<160^0$) and a missing $E_t>25$ GeV cut reduced Drell–Yan and $b\bar{b}$ backgrounds. A dilepton invariant mass cut around the Z^0 peak was used for opposite sign dielectrons and dimuons. After these cuts only three events survive (2 $e\mu$ and one ee). In a preliminary analysis the attitude was adopted to use this rate to derive a conservative lower limit to M_{top}. Assuming that all the three candidates are from top, without subtracting backgrounds, a lower limit of 108 GeV/c^2 is derived on M_{top}, at the 95% C.L.. If one combines the new data set with the 4.1 pb^{-1} collected in the previous run, the lower limit obtained on M_{top} is 113 GeV/c^2 at the 95% C.L.. We show in fig.1 the 95% upper limit of the top production cross section and its intersection at 113 GeV/c^2 with the lower limit of the theoretical cross section.

Single lepton channel with b–tag

The main background in the single lepton channel

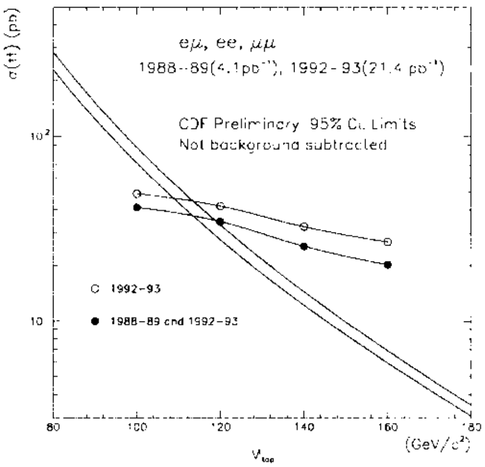

Figure 1: The experimental 95% upper limit to the $t\bar{t}$ production cross section (full points) after assuming that the observed events are top.

is from QCD W+jet events[10]. However top events should be characteri sed by the presence of two b quark s. CDF developed two techniques to tag these b's. A major boost is to exploit the information from the new Silicon Vertex Detector (SVX). The SVX can tag b–

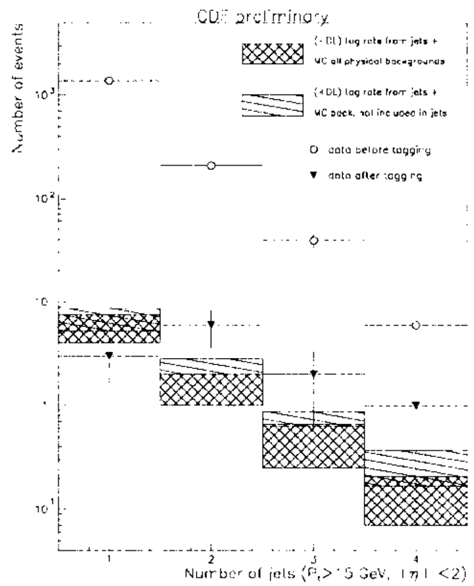

Figure 2: CDF SVX b–tagging: number of data events vs. jet multiplicity before and after the SVX tag.

flavored hadrons by finding evidence for a displaced vertex. There are several algorithms used by CDF for SVX tagging[11]. The tagging efficiency is about 25%. The average fake rate as estimated from inclusive jet events is of the order of 1.0%, but varies with E_t and track multiplicity[12]. Fig. 2 shows the number of events observed in 21 pb^{-1} of data versus the number of jets for W+jet events before and after the SVX tag. 3 tagged events with 3 or more jets are observed, when the expected background is about 1.2 events. The estimated background for lower jet multiplicities is also shown. Another method is to tag the soft electron or muon. Leptons from b–decays in $t\bar{t}$ events have low P_t and are non–isolated. CDF can identify muons with P_t>2 GeV/c (η<0.6) and electrons with P_t>1 GeV/c (η<1) The soft lepton tag efficiency in CDF is estimated at 17–22%. The fake rate is about 0.75% per muon track and about 0.5% per electron track [13].

Study of the event structure

Another approach to reduce the QCD W+jets background is to look at the event structure of QCD W+jet events and W+jet events from $t\bar{t}$ decays. These are expected to be different according to the different matrix elements of the two processes. Jets in QCD events have a strong tendency to be radiated into the forward direction, while jetsin top events tend to be more central[14]. We compared features of a "control sample" to those of a "signal sample". The data events are from the 92–93 run (21 pb^{-1}). To simulate the background, we used the Vecbos Montecarlo (W+n partons, n=1,4 with the correct matrix elements at lowest order) coupled to the SETPRT fragmentation code and the detector simulation code. In order to see whether the Vecbos Montecarlo describes properly the QCD data, a control sample was first defined by requiring three jets with E_t(jets)>20 GeV. To deplete this sample of top candidates the presence of a fourth jet was forbidden (E_t(jet_4)<15 GeV), and to enrich it with QCD events very loose rapidity cuts (|rap(jets)|<2.4) were applied. The control sample contains 23 events. The predictions of all relevant kinematic distributions agree with the data within the statistical errors. As an example E_t(all jets) for data events and Vecbos W+3 jets prediction is shown in fig. 3. The comparison of Vecbos to data was extended to a kinematical region where appreciable contribution from an heavy top might exist (signal sample). In W+3 or more jet events, the three leading jets were required to be central, with $|\cos\theta^*|$<0.8 * and |rap(jets)|<1.5. According to the Isajet Montecarlo only a small fraction of top events has a leading jet with E_t<50 GeV. The E_t cut for the leading jet was therefore raised to this value. 11 events from the 92–93 run pass these requirements out of which 8 were found to contain also a fourth jet (with E_t>14 GeV). In fig. 4 the corresponding E_t(jet_2) vs. E_t(jet_3) distribution is shown and compared to Vecbos events (W+3 jets matrix element). Data and prediction appear not to be in agreement, with the P_t spectra of data being harder then predicted by Vecbos. From top production, we would expect between 11 and 5 events for a top mass between 140 and 170 GeV/c^2 to pass these cuts, based on a cross section of 15.6 pb and 5.5 pb respectively. The WW background is expected to be less than 1 event.

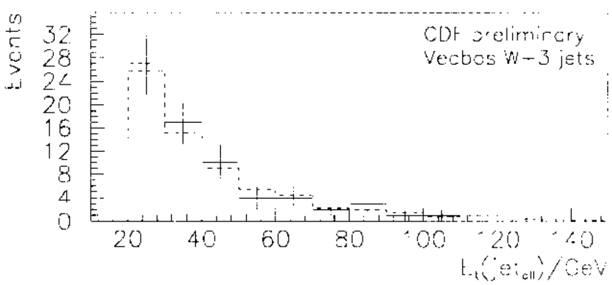

Figure 3: Et(all Jets) : Control sample. data : dots with error bars. Vecbos W+3 jets events : dotted line. Vecbos is normalised to the number of data events observed.

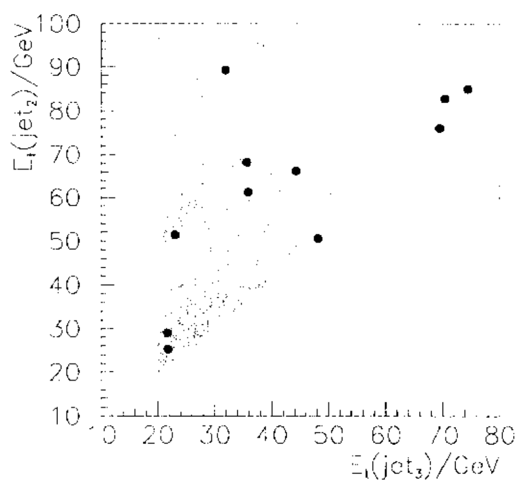

Figure 4: Event scatter plot of W+3 or more jets data (11 events) in the plane E_t(jet_2) versus E_t(jet_3) (open points) and of Montecarlo events (dots). Signal enriched sample, as explained in the text.

Conclusions

The search for exotic particles has not shown any evidence for a signal yet, but the limits are steadily improving.
The top search is progressing aggressively along various lines of attack. An improved di–lepton, an improved soft lepton b–tag, the new SVX b–tag and event structure analysis are now available. A further step will be

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*θ^* is the angle between jet and proton direction in the rest frame of the event, having ignored the ν longitudinal momentum.

soon to combine all information from these tools.

Acknowledgements

We thank the Fermilab staff and the technical staffs of the partecipating institutions for their vital contributions. This work was supported by the U.S.A. Department of Energy and national Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Science, Culture and Education of Japan; the National Science and Engineering Council of Canada; and the A. P. Sloan Foundation.
I want to thank all colleagues of the CDF Heavy Flavor Group for their help and for many inputs, and in particular G. Bellettini, H. Grassmann and S. Leone. Many thanks also to Loredana Casalis, of the "Area di Ricerca del Sincrotrone", Trieste, for her precious help in preparing my talk.

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